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Assessing the single-tree and small group selection cutting system as intermediate disturbance to promote regeneration and diversity in temperate mixedwood stands

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ABSTRACT

Traditional silvicultural systems such as clearcutting and single-tree selection cutting are critiqued for their tendency to simplify forest complexity. By more closely emulating natural disturbance regimes and increasing the availability and heterogeneity in understory light levels, we pose that systems causing intermediate disturbances such as the single-tree and small group selection cutting system can promote tree regeneration, retain stand structural attributes, and maintain high understory plant diversity in temperate mixedwood stands. To assess this, we implemented a harvest intensity gradient experiment (residual basal area [BA], % removal) consisting of uncut control (26 m^2/ha, 0%), light (21 m^2/ha, 20%), moderate (18 m^2/ha, 31%) and heavy (15 m^2/ha, 42%) cutting with retention of legacy trees in uneven-aged yellow birch (*Betula alleghaniensis* Britton) – conifer stands. We evaluated the effects on gap size, light transmittance, abundance of living and dead trees, plant diversity, and regeneration of target species (i.e. yellow birch, red spruce [*Picea rubens* Sarg.] and balsam fir [*Abies balsamea* L.]), during the 8 years postcut. Moderate and heavy single-tree and small group selection cutting treatments triggered changes in microenvironments and in understory plant community. Moderate and heavy selection had greater yellow birch seedling density > 30 cm in height compared to the control. Cutting treatments did not significantly improve red spruce and balsam fir regeneration, despite favorable micro-environmental conditions (e.g. gaps averaging 200–350 m^2 and 15–40% transmitted light). The vascular plant community rebounded quickly after disturbance and harvesting did not depress any diversity metric or alter community composition beyond control levels. Tree species richness increased in moderate and heavy selection cuts, while vascular species diversity (H′) was greatest in the heavy selection cut. Observed richness and diversity gains were driven by augmented yellow birch and mountain maple (*Acer spicatum* Lam.) recruitment into larger classes as well as greater forb, tree, and shrub cover in response to greater cutting intensities. Species richness and diversity were positively correlated with increased light availability, but not with light heterogeneity. Our results show that this hybrid selection cutting system benefits yellow birch recruitment without negatively impacting plant diversity. However, because increasing harvest intensity simultaneously enhanced interfering non-commercial species abundance (e.g. mountain maple), failed to improve red spruce regeneration, and decreased the abundance of large trees (diameter at breast height > 29 cm), we caution to opt for moderate cutting intensity in this forest type. Additional treatments such as enrichment planting in harvest gaps might be necessary to maintain red spruce over time.

1. Introduction

Traditional silvicultural systems have long been critiqued for their tendency to simplify the complexity of natural forest stands (Puettmann et al., 2009). On one end of the harvest intensity spectrum, clearcutting greatly increases and homogenizes light availability creating conditions that favor the development of single-cohort stands dominated by shade-intolerant species (Archambault et al., 1998; De Grandpré et al., 2000; Laflèche et al., 2000). Although this system can reliably regenerate high-value timber, tradeoffs include decreases in structural complexity (Chaudhary et al., 2016; Gustafsson et al., 2012), alterations of wildlife habitat and taxa (Deal, 2007; Klimaszewski et al., 2005; Work et al.,

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2010), and shifts in plant community composition (Boucher et al., 2008; Duguid and Ashton, 2013). At the other end of the spectrum, less intensive uneven-aged systems that maintain continuous canopy cover generally exert fewer negative impacts (Falk et al., 2008; Kuuluvainen et al., 2012; Rogers et al., 2018). Indeed, recent reviews have found that selection cutting systems have neutral to positive effects on plants and wildlife (Duguid and Ashton, 2013; Chaudhary et al., 2016). Nevertheless, long term application of certain variants of selection systems can reduce structural complexity and the abundance of biological legacies that are key to maintaining biodiversity (e.g. large trees, snags, coarse woody debris) (McGee et al., 1999; Angers et al., 2005; Kenefic and Nyland, 2007; Mahon et al., 2008). Less intense silvicultural systems (e.g. single-tree selection) also tend to create homogenous low light environments that favor shade-tolerant species (e.g. sugar maple [*Acer saccharum* Marsh.]) but that fail to regenerate more light demanding species (e.g. yellow birch [*Betula alleghaniensis* Britton]) (Webster and Lorimer, 2005; Domke et al., 2007; Shields et al., 2007). Thus, silvicultural systems at both ends of the harvest spectrum promote homogeneous understory light patterns that favor a restricted set of species.

Alternatively, silvicultural systems causing intermediate levels of disturbances (*sensu* Connell, 1978) could enhance resource availability and heterogeneity, thereby diversifying the array of ecological niches that can promote plant diversity and mixed-species regeneration. For example, gap-based approaches (*sensu* Coates and Burton, 1997), such as group and patch selection systems, create medium to large gaps (e.g. 300–2000 m^2) to increase both resource availability and heterogeneity with the goal of diversifying tree species regeneration (Raymond et al., 2006; Beaudet et al., 2011; Poznanovic et al., 2014). Although these gap-based systems are hypothesized to promote species coexistence, the empirical evidence for this effect has been equivocal. Group and patch selection systems can regenerate mid-tolerant and shade-intolerant species (Leak and Filip, 1977; Prévost et al., 2010; Prévost and Charette, 2015), but often fail to regenerate slow-growing, shade-tolerant conifers (e.g. red spruce [*Picea rubens* Sarg.] and eastern hemlock [*Tsuga canadensis* (L.) Carrière]; Webster and Lorimer, 2002; Prévost et al., 2010). In addition, group and patch-selection systems using large gaps are criticized for their lack of flexibility to optimize wood production, especially when applied to stands with complex structures (Raymond et al., 2016). Indeed, these systems are too often uniformly, regularly dispersing gaps throughout a stand with little consideration to the existing structural or biological conditions that may influence regeneration and maintenance of biodiversity (Puettmann et al., 2009). This approach is risky because the application of silvicultural systems without explicit recognition of the disturbance and stand dynamics characteristic to a particular ecosystem may fail to meet management objectives (O'Hara, 2002; Puettmann et al., 2015).

In contrast, silvicultural systems that create irregularly dispersed harvest gaps of variable size could create heterogeneous understory conditions favorable to mixed-species regeneration and plant diversity (Fahey and Puettmann, 2007; Kern et al., 2017). This could be the case for the hybrid single-tree and small group selection cutting system (Nyland, 2002), in which gaps are haphazardly created throughout stands, depending on the location and pattern of mature trees to harvest. Such system establishes small gaps (< 300 m^2) of variable size, thereby expanding the variety of regeneration niches that can potentially satisfy the ecological requirements of multiple species (e.g. Dumais and Prévost, 2014). Additionally, this system increases age class interspersion and promotes heterogeneous spatial and vertical structures, thus perpetuating the heterogeneous character of the community (Nyland, 2002). Although a few studies have shown the merits of this approach on tree regeneration (e.g. Bédard et al., 2014; Prévost and Charette, 2015; Walters et al., 2016), the effects on stand structural attributes and plant community diversity still need to be assessed.

With a diversity of co-occurring species from the boreal and temperate forests, late-successional yellow birch – conifer stands provide an ideal setting to assess the hybrid single-tree and small group selection cutting system. Yellow birch – conifer is the most widespread and economically important forest type in Quebec's temperate mixedwood forest, a boreal-temperate forest ecotone that extends roughly between the 47°N and 48°N parallels (Saucier et al., 2009). Similar to spruce-fir-hardwood in USA (Kabrick et al., 2017), these stands grow on rich sites where several tree species with contrasting traits coexist as a result of a long successional process characterized by frequent, yet relatively low-severity gap-phase disturbances rather than infrequent, high severity stand-replacing disturbances (Seymour et al., 2002; Duchesne and Prévost, 2012). Gap regimes in this forest type are highly variable in size and spatial distribution ($\overline{X}$ = 270 m^2, stdev = 314 m^2, range: 20–2100 m^2; Kneeshaw and Prévost, 2007). Moreover, the mixture of tree species of varying crown geometries, phenologies, and shade tolerances generates structurally complex stands that often exhibit greater heterogeneity in understory light conditions than in hardwood or conifer stands (Brown and Parker, 1994; Bartels and Chen, 2010; Macdonald and Fenniak, 2007). Indeed, Bartels and Chen (2010) hypothesized that in mixedwood stands, heterogeneity of light conditions may be more important than light availability itself for regulating understory plant species diversity and coexistence, relative to hardwood or conifer stands.

Here, we test the hypothesis that a hybrid single-tree and small group selection system, by more closely emulating natural disturbance regimes and increasing the availability and heterogeneity in understory light levels, will promote regeneration of target species (i.e. yellow birch, red spruce and balsam fir [*Abies balsamea* L.]), retain stand structural attributes, and maintain high understory plant diversity. Furthermore, by implementing this variable harvesting regimen across a range of cutting intensities we explore whether an optimal harvest intensity exists to achieve desired regeneration outcomes and retain structural and biological legacies.

2. Materials and methods

2.1. Site description

We conducted this study north of Saint-Raymond (46°58′N, 72°02′E), approximately 80 km northwest of Quebec City, Canada. The region is characterized by a high-hill topography with rounded summits and the prevalence of glacial tills (Robitaille and Saucier, 1998). Mean monthly temperatures (1981–2010) vary from −14.6 °C in January to 17.3 °C in July (using BioSIM; Régnière and Bolstad, 1994). On average, the region receives 1253 mm of precipitation annually, with 31% falling as snow. The experiment was established in late-successional uneven-aged yellow birch – conifer stands, at the margins of the balsam fir – yellow birch and the sugar maple – yellow birch bioclimatic domains (Saucier et al., 2009). The natural disturbance regime is characterized by light to moderate partial disturbances occurring between stand-replacing disturbances (fire at 200–400 year return) (Boucher et al., 2011). Background mortality and insect outbreaks (e.g. spruce budworm [*Choristoneura fumiferana* (Clemens)], hemlock looper [*Lambdina fiscellaria* (Guenée)]) cause partial mortality that induces gap regeneration (Bouchard et al., 2006; Barrette and Bélanger, 2007; Kneeshaw and Prévost, 2007).

Before the cut, stand merchantable basal area (BA of trees > 9 cm dbh [diameter at breast height]) averaged 25.7 m^2/ha (± 3.6 m^2/ha SD, n = 20) and was composed of 42% yellow birch, 20% red spruce, 16% balsam fir, 12% sugar maple, and 6% red maple (*Acer rubrum* L.). Companion species including paper birch (*Betula papyrifera* Marsh.), American beech (*Fagus grandifolia* Ehrh.), American mountain ash (*Sorbus americana* Marsh.), pin cherry (*Prunus pensylvanica* L.f.), striped maple (*Acer pensylvanicum* L.), and mountain maple (*Acer spicatum* Lam.) constituted the remaining 4%. Dendrochronological analyses of trees sampled at 1 m-height indicated the mature canopy trees had attained ages of up to 100, 140, and 200+ years for balsam fir, yellow